THE HYDROACOUSTIC COMPONENT OF AN INTERNATIONAL MONITORING SYSTEM

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ABSTRACT: The critical issue for the hydroacoustic component of an International Monitoring System (IMS) is its capability for monitoring nuclear explosions in the world's oceans. Factors that affect this capability are number and location of hydroacoustic sensors, placement of sensors, blockage of the hydroacoustic signal due to bathymetric effects, and spatial and temporal variation in hydroacoustic signal propagation due to changes in oceanic properties. This paper provides examples of hydroacoustic monitoring capability from historical data that demonstrates the impact of these factors, and discusses implications from these results on design of a hydroacoustic network.

Specific data processing examples of hydroacoustic detection and discrimination capability are given for hydroacoustic signals from earthquakes and explosions recorded at MILS (Missile Impact Location System) and other hydrophones in the Atlantic and Pacific Ocean. In the 1960's, the United States (U.S.) Navy performed a series of ship sinking explosions underwater as well as a set of explosions that traversed the Aleutian Island chain at a ninety degree angle. Another study is of more recent data from a collection of earthquakes south of Australia and in the Southern Pacific Ocean. Examples from all of these data illustrate the blockage effects due to the bathymetric profile and effects of hydroacoustic sensor emplacement on the side or top of, or floated from the top of seamounts into the SOFAR (Sound Fixing and Ranging) channel on hydroacoustic signal strength.

These data processing examples also demonstrate the high degree of confidence achieved in the discrimination between earthquakes and explosions based on their respective frequency content and presence or absence of an explosion-produced bubble pulse signal. The explosion data exhibit significant frequency content up to the anti-alias filter frequency of seventy Hertz, while the earthquake data shows severe attenuation beyond 20 Hertz and no bubble pulse signals. Potential problems are hydroacoustic signals from volcanic explosions that exhibit explosion-like characteristics and from vented explosions or explosions just above the ocean's surface.

The paper recommends that these historical data provide a basis for a knowledge grid of the ocean that would define for each hypothetical explosion source position (for example, on a one- by one-degree or finer grid) what a hydroacoustic sensor would expect to see. The knowledge grid would contain information from both theoretical detection and location capability models and this type of observed historical data. This could ultimately be combined with a similar seismic and possibly infrasonic knowledge grid to give worldwide detection and location capability for subsurface and low atmospheric nuclear explosions. The paper concludes with a design for the hydroacoustic component that takes into account the use of a combination of assets for monitoring nuclear explosions on a global scale that include seismic, infrasonic, and hydroacoustic networks.

INTRODUCTION: The oceans cover over 70 percent of the earth's surface with much of the seismic activity from earthquakes and volcanic activity occurring along coastlines, in oceanic ridges, and in the Pacific and Indian Ocean trenches. Hydroacoustic signals propagating from these and other explosion-type oceanic events provide a high-confidence method for monitoring a Comprehensive Test Ban Treaty (CTBT) in the world's oceans. A hydroacoustic system would work in combination with the existing seismic and proposed infrasonic systems to detect, locate, discriminate, and estimate the yield of fully-contained and vented explosions, and explosions just above the ocean's surface.

Several factors contribute to the robust monitoring capability provided by a hydroacoustic system. It is well known and understood that hydroacoustic signals propagate most efficiently as a waveguide phenomena in the SOFAR channel where the sound velocity is at its axis; this results in excellent signal-to-noise ratios for even small events travelling over thousands of kilometers. The velocity of propagation is relatively constant over the broad ocean areas and slow compared to seismic velocities which gives improved location accuracy for oceanic events detected and located by denser seismic and infrasonic systems. The false alarm rate for discriminating fully-contained and vented underwater explosions from submarine earthquakes is low because of the presence of high frequencies beyond 20 Hertz (Hz) in the former case but not the latter one. In addition, fully-contained explosions are uniquely discriminated by bubble pulse signals in the hydroacoustic data; these characteristic signals are produced from expansion and contraction of the gas bubble while it rises to the ocean's surface and are clearly evident even after propagating great distances through the sound channel.

BACKGROUND: At present, there are two fixed-cable hydroacoustic stations offered by the United States as part of the hydroacoustic component of the IMS. These two stations, Wake Island in the Pacific and Ascension Island in the Atlantic, give significant hydroacoustic detection and discrimination capability on a worldwide, oceanic basin scale because of the efficient transmission of sound through water. Each of these stations have unique features that contribute to their excellent monitoring capability. At both the Ascension and Wake Island stations, there are hydrophones far from and near to the islands, all of which are in the SOFAR channel. There are also bottom-mounted hydrophones; however, at Ascension Island, their cable is cut and buried at the shoreline.

The hydrophones at these stations that are far away from the islands in the SOFAR channel are those most useful for detecting explosion signals. The hydrophones closest to the islands but still in the SOFAR channel also are useful in detecting explosion signals but suffer some signal-to-noise reduction from current-induced noise, interfering modes from reflections off the islands, and shadowing effects. The Heard Island Feasibility Test in 1991, in which controlled sources were transmitted in the SOFAR channel from Heard Island in the southern Indian Ocean, demonstrated that attenuated signals were recorded even on hydrophones closest to Ascension Island in the Atlantic Ocean on the back side to the source. The hydrophones on the bottom at these sites are the least useful for detecting explosion signals. These hydrophones are essentially ocean bottom seismometers and are redundant to the planned seismic network. They are also buried in loosely compacted sediment which decouples them from the environment and leads to signal strength loss.

Another type of hydroacoustic asset considered by the IMS but not offered by the U.S. is the sonobuoy configuration. In this case, a hydrophone is suspended from a floating buoy or floated from a moored buoy into the SOFAR channel. This sonobuoy design is essentially in the research and development stage, at present, and not a proven concept particularly for operations in remote regions of the oceans. Typically, present day sonobuoys of this type are used for short time duration experiments to avoid the expense associated with servicing and replacement of the units.

RESULTS: There were a number of experiments done in the 1960's involving underwater explosions whose hydroacoustic signals were recorded on MILS hydrophones at the Wake and Ascension Island facilities as well as other hydrophones. The processed data from these explosions demonstrate the unique capability provided by hydroacoustic assets in a monitoring regime. In particular, these data emphasize the effects of source and receiver blockage as well as sensor position on hydroacoustic signal strength. Comparisons between these explosion data and signals from underwater volcanic eruptions also illustrate problem areas where further research is necessary to resolve discrimination issues.

The first set of data presented is from a series of underwater shots that the U.S. Navy detonated in 1967 on a line that intersected Amchitka Island in the Aleutian Islands. These data were recorded on MILS hydrophones in the Pacific ocean and demonstrated that 1) even with local and long-range partial blockage, the bubble pulse signal was observed at nearly 5000 kilometers, and that 2) bathymetric effects on less than a degree-by-degree scale were important in hydroacoustic signal strength. One series of these explosions was done above, in, and below the SOFAR channel. These data exhibit the expected largest amplitude for the shots in or near the axis of the SOFAR channel.

The second set of data is from a ship (CHASE) explosion off the New Jersey coast that was recorded on both bottom and SOFAR channel MILS hydrophones that were in proximity at Ascension Island. As expected, the hydrophone signal recorded on the SOFAR channel was higher in amplitude than that on the bottom one, but no loss in frequency content, at least to 70 Hz which was the anti-alias cutoff frequency, was observed.

The third set of data is from another CHASE explosion off the California coast that was recorded on Pacific MILS hydrophones. These data were compared to hydroacoustic signals from earthquakes and volcanic eruptions. The major difference between the explosion and earthquake data was in frequency content; the signals from earthquakes were severely attenuated beyond 20 Hz while those from explosions retained significant frequency content up through 70 Hz. The difference in frequency content was not as pronounced between the explosions and volcanic eruptions. The volcanic eruptions are essentially explosive in nature and produce bubble pulse signals, however, the associated hydroacoustic signals are more complex in nature and longer in duration than signals from man-made explosions.

DISCUSSION: The U.S. has proposed a six-station hydroacoustic network to the international community that includes the MILS at Wake and Ascension Island as the U.S. contribution and is capable of recording the types of hydroacoustic signals described in the results section. This network has two stations in each ocean basin principally in the Southern Hemisphere which accounts for the concentration of seismic and radionuclide and other monitoring assets in the Northern

Hemisphere. The network specifically consists of one station each in the southernmost Atlantic and Pacific Oceans, and two in the Indian Ocean as well as the two MILS stations and is illustrated in Figure 1.

This hydroacoustic network, if used in combination with the seismic and proposed infrasonic networks, would provide for detection, location, and discrimination of oceanic events above, at, and below the seismic threshold on a worldwide basis. For oceanic events above the seismic threshold, the hydroacoustic system would provide high-confidence discrimination and improved location of oceanic events. In particular, it would discriminate submarine earthquakes by the absence of high frequency content and bubble pulse signals. The lower uncertainty for hydroacoustic relative to seismic travel times combined with a much lower slowness for the hydroacoustic signal would give improved location estimates, particularly for events in the Southern Hemisphere.

The likely scenario for events below the seismic threshold is that of an explosion in the Southern Hemisphere just above the ocean's surface which should record on multiple infrasonic stations for a one kt explosion. The corresponding infrasonic detections which have a low false alarm rate based on historical evidence would provide azimuths and an approximate origin time for the event. The hydroacoustic travel time prediction should then effectively separate the associated hydroacoustic signals that have illuminated the Southern Hemisphere because of the unique features of the SOFAR channel from false alarm signals due to limited industrial activity that may have also occurred. Azimuths from these infrasonic detections combined with even one associated hydroacoustic travel time that was predicted by these data should significantly improve the location estimate for the event.

CONCLUSIONS and RECOMMENDATIONS: The proposed hydroacoustic network in Figure 1 would provide high-confidence evidence that a one kt explosion had occurred in the world's oceans when operated in a real-time mode. In an event-driven mode, the hydroacoustic system could act in a complementary fashion to the seismic and infrasonic systems for events above and below the seismic threshold, respectively. This would give high-confidence discrimination of submarine earthquakes and improved location estimates for seismic and infrasonic events.

Research studies are required to quantify the improved detection, location, and discrimination capability afforded to the IMS by the hydroacoustic component. Studies should continue on the effects of a number of factors on local hydroacoustic signal strength and long-range hydroacoustic wave propagation. The local effects include current-induced noise and the pinch-out of the SOFAR channel right around islands. Long-range wave propagation effects include partial blockage of the hydroacoustic wave from islands or seamounts that intersect the SOFAR channel as well as lateral heterogeneities in oceanic properties. Once the effects of these factors on hydroacoustic signal strength are quantified, a knowledge grid could be set up for the ocean that would define for each hypothetical explosion source position what a sensor would expect to see. The knowledge grid would contain information from both the theoretical capability models and the types of observed historical data presented here. This could ultimately be combined with a similar seismic and possibly infrasonic knowledge grid to give worldwide detection and location capability for subsurface and low atmospheric nuclear explosions.

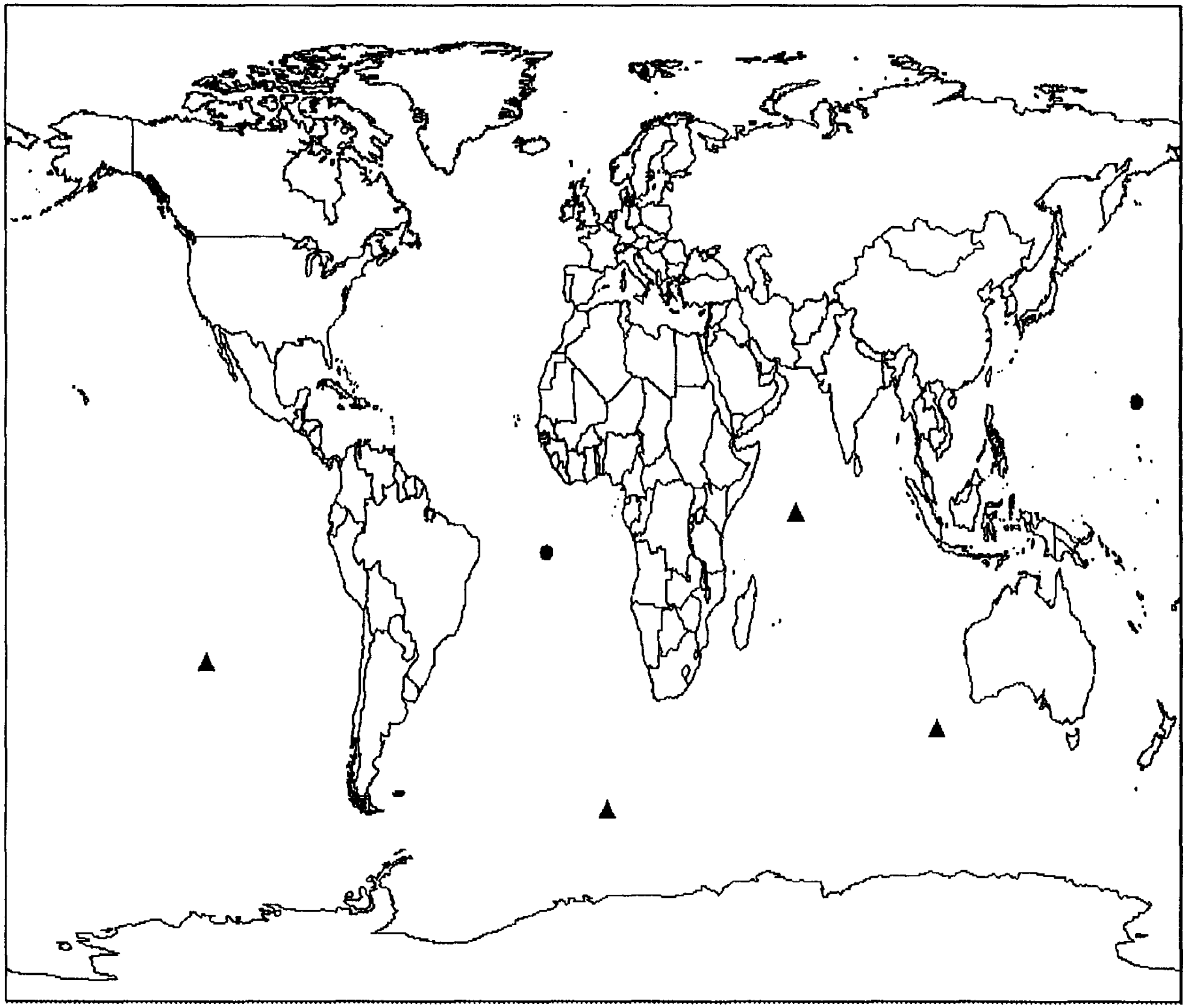

Figure 1. Proposed hydroacoustic component for the International Monitoring System. Circles are MILS hydrophones at Ascension and Wake Island and triangles are the proposed hydroacoustic stations.